U. S. Naval School of Aviation Medicine

U. S. NAVAL AIR STATION
PENSACOLA, FLORIDA

RESEARCH REPORT

INTELLIGIBILITY OF SPEECH HEARD AT HIGH ALTITUDE AND SEA LEVEL

REPORT NO. NM 001 064.01.14

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U. S. Naval School of Aviation Medicine — 30 October 1952

Joint Report NM 001 064.01, Report No. 14

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Chester J. Atkinson, PhD., Acoustic Laboratory, U. S. Naval School of Aviation Medicine, NAS, Pensacola, Florida

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U. S. NAVAL SCHOOL OF AVIATION MEDICINE
NAVAL AIR STATION
PENSACOLA, FLORIDA

JOINT PROJECT REPORT NO. 14

The Ohio State University Research Foundation
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INTELLIGIBILITY OF SPEECH HEARD AT HIGH ALTITUDE AND SEA LEVEL

Report prepared by

Chester J. Atkinson

Approved by

John W. Black
Project Director
and
Captain Ashton Graybiel, MC, USN
Director of Research
U. S. Naval School of Aviation Medicine

Released by

Captain James L. Holland, MC, USN
Commanding Officer

30 October 1952

INTELLIGIBILITY OF SPEECH HEARD AT HIGH ALTITUDE AND SEA LEVEL

SUMMARY

Four groups of speakers in units of 10 per group took part in speech intelligibility testing conducted during altitude runs in a low pressure chamber taken to 43,000 feet. Approximately one-half of each panel served as speaker-listeners at altitude and the other half functioned at sea level only as listeners. The speech materials were multiple-choice intelligibility tests from Forms A, B, C and D. Each group made some 15 altitude runs of one-half hour at altitude. Speaker scores at altitude, listener scores at altitude, as well as listener scores at sea level, were obtained. Listening was done monaurally, one ear open to ambient sounds. The unit at altitude had a noise environment of 110 db simulated aircraft noise, the unit at sea level in chamber room ambient noise.

SUMMARY OF RESULTS

1. Speakers at altitude, speaking against pressurized oxygen, received response scores that generally increased from Day 1 to Day 15. The variance due to days was significant for all groups.

2. Listener scores at sea level and at altitude were not different at a statistically significant level. Group Four, however, approached the 5 percent level of confidence.

3. It was observed that speaking at altitude tended to restore O_2-CO_2 balance in the blood.

INTRODUCTION

Speech intelligibility tests were conducted during a series of simulated high altitude runs at the U.S. Naval School of Aviation Medicine.* The purpose was to test how well speakers were able to make themselves understood over an aircraft intercommunication set while at 43,000 feet and breathing pure oxygen at 10 inches of water pressure.

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* The main purpose of the series of altitude runs was to chart the effects of this altitude and decompression upon arterial blood saturation. Electrocardiograms and X-rays were also taken. The results are reported in U.S. Naval School of Aviation Medicine Project No. NM 001 059.21.02, "The Effects of Decompression on Subjects Repeatedly Exposed to 43,000 Feet While Using Standard Breathing Equipment", by LCDR A.L. Hall, MSC, USN and Madhukar Shrinagesh, Indian Air Force.

Two lines of investigation have been reported that apply quite directly to the problem of speech reception at high altitudes. One deals with the resistance to change displayed by the threshold of hearing at high altitude. Another deals with articulation scores that were reported to decrease with altitude up to 37,000 feet. "Intelligible speech" was reported at 43,000 feet.

Examples of the usual decrement of articulation scores with increasing altitude are the following. From the Psycho-Acoustic Laboratory, in an OSRD report (1) the following table is given:

	Plane	
	B 17	B 24
At 5,000 feet, articulation scores, in percent	73	76
At 35,000 feet, articulation scores, in percent	65	66

In the same report is the following table. The differences in scores in the vertical columns are due mostly to differing equipment over which the tests were given. The tests were given during actual flights. The results are in percent articulation scores.

Altitude		
5,000 feet	33,000 feet	Alt. Differential
21.2	10.4	10.8
26.6	17.6	9.0
29.2	25.6	3.6
40.3	32.0	8.3
65.1	54.0	11.1
72.5	64.4	8.1

The Psycho-Acoustic Laboratory states in another OSRD report (2):

There was a gradual dropping off in articulation up to approximately 20,000 feet, with a sharper drop in articulation scores at progressively higher altitudes. The detrimental effect of high altitudes was much more serious than is indicated by the scores, because the speaker unconsciously compensated for altitude loss by increased effort in speaking. Great effort is required for a speaker to make himself understood at 33,000 feet. After only a few words, the speaker runs out of breath. The speaking of complete sentences at an adequate voice level proved to be exceedingly difficult at high altitude. It was concluded that remarkably consistent gain deficit as a result of going to altitude is shown. This deficit ranged between 13 and 20 db.

One of the same reports cited above reported a dissimilar phenomenon. Preliminary investigations indicated that the sensitivity of the ear itself does not change appreciably between sea level and 35,000 feet. This resistance to change exhibited by the threshold of the ear at different altitudes was also reported by Rudmose, et al. (3): "In view of the results--it must be concluded that the average threshold of hearing is . . independent of the density of the air in the outer and middle ear". This conclusion was based on threshold tests at sea level and at 35,000 feet simulated altitude.

Fletcher (4) has advanced as a working hypothesis that a hearing threshold measure is a relatively good measure of speech reception ability. If this is true, the speech reception scores at altitude should be roughly equivalent to the same speech received at sea level.

The results of articulation scores decreasing with increasing altitude, and the stability of the threshold of hearing at differing altitudes coupled with the relationship that appears to exist between the threshold of hearing and speech reception ability lead to the formulation of an hypothesis: Listener's intelligibility scores at sea level are not different from listener's intelligibility scores at altitude when the same speech signal is heard by both. Another hypothesis emenable to test by the design of the same experiment was: The speaker scores on successive altitude runs are not dissimilar.

PROCEDURE

The speech tests were necessarily fitted into a half-hour program of operations after 43,000 feet was reached, that included X-rays, oxygen saturation tests, and oxygen consumption tests. An important limiting factor in conducting the speech test was the fact that the same intercom served for testing and for all communication in and out of the altitude chamber. This limited the testing to about 15 out of each series of 20 altitude runs made by each of four groups of speakers.

Speakers in groups of ten went through the following routine. About one half of each group (as many as six, as few as three) preoxygenated for one half-hour in the altitude chamber. After the period of preoxygenation, the chamber was taken to indicated 43,000 feet and held there for a period of one half-hour unless a health hazard intervened. During this half-hour, each person at altitude read an intelligibility list and the rest of the group at altitude served as a listening panel. The group who remained at sea level served as a separate listening panel.

Each man was issued a helmet with one earphone (ANB-H-1A). The other earphone was removed to allow the earpiece of the oximeter to be positioned. These helmets were fitted individually with great care as a precaution against any leaks of the oxygen under pressure. Each man wore only his own helmet and therefore the same earphone at altitude; he also wore the same helmet at sea level. This meant that one ear was covered by an earphone and the other ear was always open to ambient sounds.

A noise generating system was provided in the altitude chamber. It was designed to deliver 110 db sound pressure level of simulated aircraft type noise in the chamber at sea level. Component parts were a Harvard Noise Generator and an 805 A Jensen speaker. No direct measurements of the sound pressure levels were made while the chamber was at altitude. The direct effect of the noise upon the speech to noise ratio at the microphone was small at sea level, because of the effective noise seal afforded by the oxygen mask. At high altitudes, the noise was even less effective because of the lowered output level of the loud-speaker in rarified air. The effects of the noise generating system were, therefore, a possible attenuation of the listener's scores at altitude through the masking effect of the noise on the uncovered ear and under the cushion of the covered ear, plus an effect upon the voice of the talker due to his noisy environment.

An RL24C Navy Intercommunication-system was used. It consisted of six stations inside the chamber for speaking and listening, six stations outside for listening only, and six stations outside for speaking and listening. Five of these speaking-listening posts were used by the chamber operator and observers. The other outside speaker-listener station was provided with a bridge output junction for recording. The experimenter was stationed at this last position. He was able to make consisent sampling tape recordings of the speech test and to direct the speech testing procedure to fit into the other tests being made--X-rays, oximeter readings, etc.

Multiple choice intelligibility test developed by Haagen (5) (VCL:MC Forms A and B) and Black (6) (Forms C and D) provide four forms of 12 speaker lists each. Each list of of comparable difficulty within a pair of forms. The two pairs of forms are also rather close (about seven percentage points apart) in mean difficulty. These tests yield scores quickly and are stable from talker to talker. The requirement of the listener in these tests is simply to cross a line through one of the four alternative words for each test word spoken. These intelligibility tests were chosen for a test measure for several reasons, lack of physical exertion while taking the tests, ease of scoring, and relative speed of the testing procedure.

The multiple-choice intelligibility lists were divided in half so that each talker at altitude would have to say approximately 14 test words. With carrier phrases, his total speech during the test amounted to about 20 words. Sub-division of the lists was based on an estimate that this number of words might approximate a mean number that an average speaker could utter within the limitations imposed upon this testing situation. In practice, it was found that most of the talkers were able to say more words, but in order for all the potential talkers to have a turn as a test speaker during a run, the number was close to a maximum.

At the end of the preoxygenation and before the altitude run started, a pencil, a 5" x 8" speaker card with the words to be read on it, and a response sheet were given to each man in the chamber. Response sheets were distributed to the outside listening stations that were manned during each run. These precautions were taken to make the testing procedure simple and straightforward. The precautions were found to be necessary during the first few runs, as a misplaced pencil or speaker card was hard to locate while the groups were at altitude.

RESULTS

The tests were scored in percentage of correct responses. The scores from the listeners at altitude were compared with the scores from the listeners at sea level. Appropriate analyses were applied to ascertain whether there was improvement of intelligibility with practice. The percentage scores of each of the four groups were compared. Most of the important results can be demonstrated by referring to a tabulation of the mean scores of the groups of subjects by days (see Table 1).

All the groups start low at Day 1 and rise generally in percentage of correct responses through Day 15. The curve representing day-by-day values is shown in Figure 1 for the mean of all four groups.

Analyses of variance were run on as much of the data of each group as were comparable. That is, data from as many subjects for as many days as possible were used to get an estimate of the significance of the changes noted. The variance due to days was significant in all four groups. This gave reason to reject the hypothesis that speaker's scores would not vary from day to day. The variance due to the differences between the sea level and altitude groups was small and non-significant for all four groups. Hence, this gave no reason to reject the hypothesis of no difference between the sea level and altitude groups. The summaries of these analyses are shown in Tables 2, 3, 4 and 5.

An interesting result is shown by the division of the listener scores each day according to whether the listeners were at sea level or at altitude. The mean scores between the sea level and altitude are similar, indicating only a slight difference between the score made at altitude and the score made at sea level while listening to the same speaker. The general result was found to be common to the four groups as shown in Figure 2. The means of the sea level scores of Group Four are seen to be somewhat higher than those of the altitude counterparts. As seen in the statistical summaries, these differences approach the 5 percent level of confidence within that group. Nevertheless, an inspection of the scores of the series of four groups lends no support to a conclusion that listeners at sea level have a decisive advantage over listeners at altitude. This is borne out by the statistical comparisons.

A sidelight of the speech tests was the observation that generally the oxygen content of the blood of the speaker was affected beneficially while speaking against pressure at altitude. For example, a speaker with low O_2 content was likely to raise his O_2 content during the minute or so that he talked. Or, if the speaker had a high O_2, e.g. 95 percent, he was likely to lower the O_2 content during speech. A stabilization of the O_2 content after approximately ½ minute of speech was usual. The incidental effects that were observed of speaking at altitude were for the most part salutory. A full report of the physiological phenomena observed during speech at altitude are given in the report by Hall and Shrinagesh (7). The fact that these incidental effects were observed is a recommendation for cooperation in research of various activities.

DISCUSSION

Speech is practically unintelligible when a talker is first confronted with the problem of speaking against pressure at altitude. There is great exertion required to compress the air in the lungs uufficiently to activate the vocal cords and overcome the pressure in the mask. The excursion of the rib cage is very evident even to an untrained observer. It is an interesting note that this violent exercise was never subjectively blamed for the cramps or "bends", while such minor movements as crossing out a word on the response form were sometimes listed as a cause of the "bends". (7).

The increase in intelligibility from 50 percent to 75 percent was dramatic enough to be remarked upon by the operators of the chamber. When each group was making the first few runs, verbal communication out from the chamber at altitude was so poor that hand signals and head movements served as signals. This condition never obtained for the messages from the operators of the chamber to the occupants at altitude. The occupants of the chamber never reported a failure to hear clearly a message from outside the chamber.

The near equality of the scores of the listeners at sea level and those at altitude in the present study indicates that some factor other than altitude alone caused the difference in the scores at increased altitude in the earlier reports.

Perhaps differences in procedure in the experiments account for the seeming difference in results. In the Harvard studies, the sea level speech reception scores were determined by an articulation team; then the whole team in an airplane went to altitude and repeated like tests at several altitudes. The apparent discrepancy among the results of the two experiments may be due to this difference; the speakers were at various altitudes in the Harvard studies and not at different altitudes in the present study.

The results of the studies appear to be in harmony if the assumptions are made that a listener's performance is essentially the same at any altitude, and that a speaker's performance suffers in proportion to the altitude at which he speaks. The first assumption is well supported by the experimentation on thresholds already cited, and Fletcher's article (4). The last assumption is supported by a priori considerations as well as the decrements in articulation scores for increasing altitude reported in the Harvard series.

As a general rule, the more participants in an altitude run, the chances are increased that the run may be forced down due to gas pains, bends, etc. Relevant to this generality, an implication from the study is that speakers need to be sent to altitude for practice training to make their speech more intelligible. However, there appears no good reason to train listeners at altitude. This last implication may result in a considerable saving in altitude runs by carrying persons along to serve as a listening panel for speakers at altitude. This information should lead to a conservation of time and oxygen by allowing listeners to be at sea level outside the chamber.

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TABLE I

Means of Intelligibility Scores of Four Groups of Subjects by Successive Days at 43,000 Feet.

The scores are subdivided according to whether the listener was at sea level or at altitude.

	Group 1		Group 2		Group 3		Group 4	
Days	SL	Alt.	SL	Alt.	SL	Alt.	SL	Alt.
1	41.0	41.5	65.3	57.8	38.3	47.0	61.2	57.8
2	67.7	58.7	63.3	63.5	47.5	53.7	62.6	66.7
3	61.4	68.2	66.0	68.0	56.6	59.6	63.4	64.1
4	72.5	69.5	67.6	52.0	61.2	54.2	62.6	66.7
5	68.3	66.5	66.2	44.2	63.6	60.3	59.8	61.2
6	68.9	59.8	59.5	55.5	57.5	58.5	59.5	67.2
7	66.7	64.6	66.0	62.6	61.3	57.2	58.8	63.1
8	73.6	73.2	62.7	60.2	64.8	64.0	67.1	69.8
9	67.7	64.0	65.2	64.0	68.3	59.8	70.7	64.4
10	58.7	62.5	76.5	68.3	64.6	63.5	65.8	65.8
11	69.4	75.2	66.7	69.0	61.3	64.5	68.1	64.3
12	68.0	66.1	75.4	69.2	63.7	69.5	72.8	69.7
13	70.4	73.0	87.0	89.5	66.4	65.1	68.8	74.2
14	72.2	68.2	78.5	91.5	63.4	56.6	61.2	69.4
15	82.5	76.0	78.2	77.5	61.3	54.0	61.5	55.2

TABLE II

Summary of Analysis of Variance, First Group: Basic Measures, Percent of Intelligibility of Four Listeners for Ten Altitude Runs

Source	d.f.	Sum of Squares	Variance	Error Term	F
Sea Level - Altitude	1	74	74	229	.32
Listeners	3	874	291	229	1.27
Days	9	5058	562	229	2.45 *
SA x L	3	55	18		
SA x D	9	466	52		
L x D	27	4090	152		
SA x L x D	27	6180	229		
Total	79	16797			

* Significant at the 5% level of confidence (2.25, 9 and 27 d.f.).

TABLE III

Summary of Analysis of Variance, Second Group: Basic Measures, Percent of Intelligibility of Six Listeners for Nine Altitude Runs

Source	d.f.	Sum of Squares	Variance	Error Term	F
Sea Level - Altitude	1	63	63	58	1.09
Listeners	5	1541	308	114	2.70 **
Days	8	3820	478	114	4.19 ***
SA x L	5	289	58		
SA x D	8	922	115		
L x D	40	4553	114	58	1.97 *
SA x L x D	40	2301	58		
Total	107	13489			

* Significant at the 5% level of confidence (1.69, 40 and 40 d.f.).

** Significant at the 5% level of confidence (2.45, 5 and 40 d.f.).

*** Significant at the 1% level of confidence (2.99, 8 and 40 d.f.).

TABLE IV

Summary of Analysis of Variance, Third Group: Basic Measures, Percent of Intelligibility of Four Listeners for Eleven Altitude Runs

Source	d.f.	Sum of Squares	Variance	Error Term	F
Altitude - Sea Level	1	27	27		
Listeners	3	3605	1202	289	4.16 ***
Days	10	4858	486	289	1.68
SA x L	3	346	115		
SA x D	10	1145	115		
L x D	30	8669	289	68	4.25 **
SA x L x D	30	2039	68		
Total	87	20689			

** Significant at the 1% level of confidence (2.38, 30 and 30 d.f.).

*** Significant at the 1% level of confidence (2.98, 10 and 30 d.f.).

TABLE V

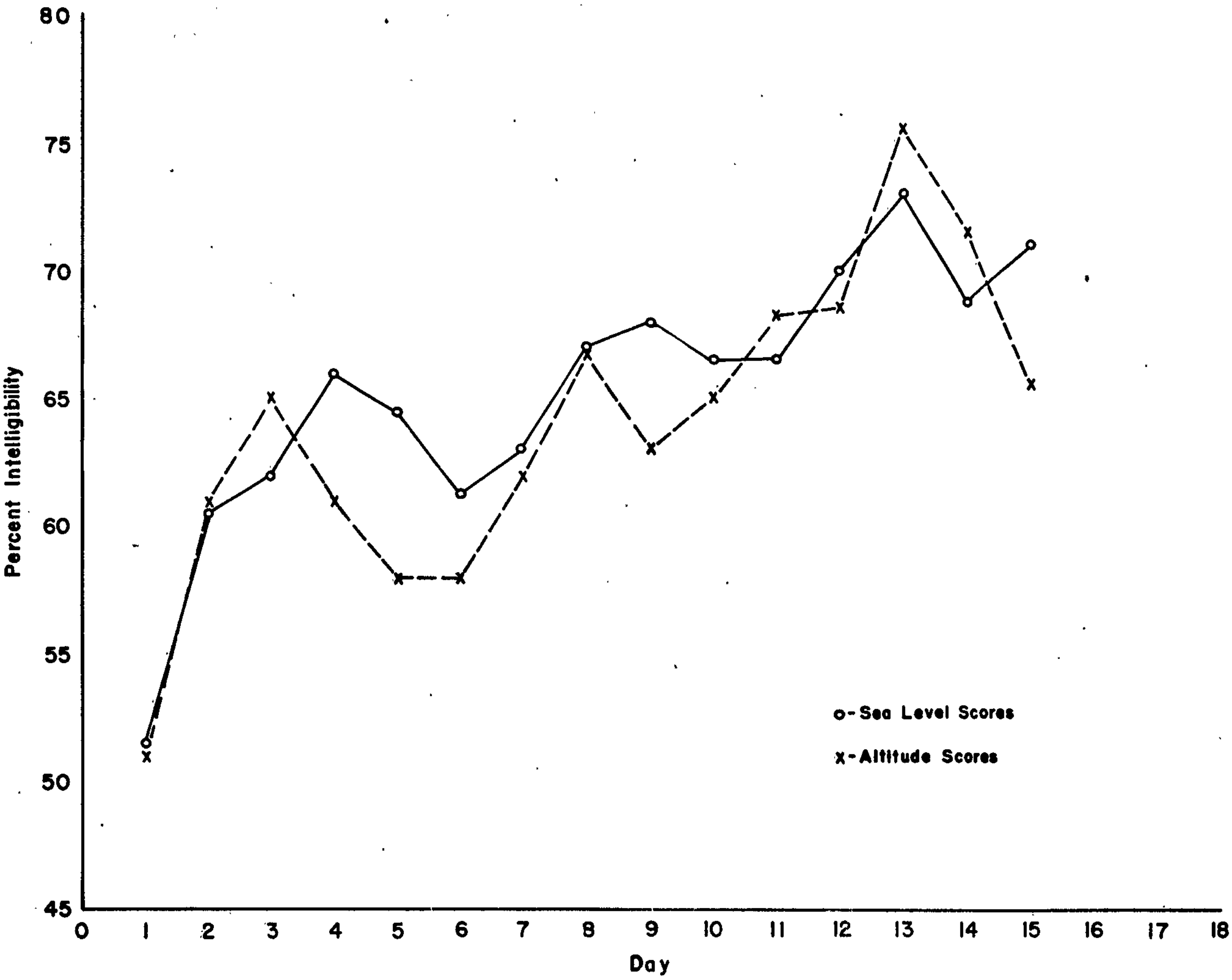
Summary of Analysis of Variance, Fourth Group: Basic Measures, Percent of Intelligibility of Seven Listeners for Nine Altitude Runs

Source	d.f.	Sum of Squares	Variance	Error Term	F
Altitude - Sea Level	1	122	122	61	2.00
Listeners	6	3675	613	155	3.95 ***
Days	8	3448	431	155	2.78 *
AS x L	6	308	51		
AS x D	8	657	82		
L x D	48	7438	155	61	2.54 **
AS x L x D	48	2950	61		
Total	125	18598			

* Significant at the 5% level of confidence (2.14, 8 and 48 d.f.).

** Significant at the 1% level of confidence (2.02, 48 and 48 d.f.).

*** Significant at the 1% level of confidence (3.20, 6 and 48 d.f.).



PLOT OF THE MEANS OF THE SEA LEVEL AND ALTITUDE INTELLIGIBILITY SCORES DAY BY DAY

FIGURE 1